

# Shanghai VLBI Correlator 2017–2018 Biennial Report

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**Abstract** This report summarizes the activities of the Shanghai VLBI Correlator during 2017 and 2018. Highlights include the peculiar clock offset compensation, CVN and K5 correlators comparison, 4-Gbps data e-transfer, VLBI Ecliptic Plane Survey, 2-Gbps experiments at S/X, K-band fringe tests for Tianma65, and RadioAstron space VLBI fringe test.

## 1 Introduction

The Shanghai VLBI Correlator is hosted and operated by the Shanghai Astronomical Observatory (SHAO), Chinese Academy of Sciences (CAS). It is located at the Sheshan campus, about 40 kilometers from the Xujiahui headquarters of SHAO. The Shanghai correlator has been used in the data processing of the Chinese VLBI Network (CVN), including the CMONOC project for monitoring the Chinese regional crustal movement, and the Chinese deep space exploration project for spacecraft tracking.

As shown in Figure 1, Shanghai (including Sheshan25 and Tianma65), Kunming, and Urumqi participate in international and domestic VLBI sessions, while the Beijing station is mainly used for spacecraft data downlink and VLBI tracking.

The Shanghai correlator was accepted as an IVS correlator in March 2012. It began to correlate IVS data

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using the DiFX software correlator in 2015. In the long run, our goal is to correlate a weekly IVS observing session on a regular basis.



**Fig. 1** Distribution of the VLBI stations in China.

## 2 Component Description

We are operating two types of correlators. The CVN correlator developed by SHAO has been operational since 2006. It is mainly used for spacecraft VLBI tracking in the Chang'E lunar exploration project by producing differential VLBI observables. The data latency is less than one minute in real-time mode, and the typical accuracy is better than 1 ns. It was used to correlate a few tens of Chinese domestic geodetic sessions before 2014. The other one is the DiFX software correlator,

which is dedicated to astrophysical and geodetic data correlation.

The DiFX software was installed on a powerful hardware platform in December 2014, with a 420 core cluster system and a 400-TB storage space. The disk array was expanded to 800 TB in 2018 to meet the requirement of increased data volume. Three Mark 6 units were installed and are under testing. The suite version is Mark6\_1.3c with dplane as 1.22 and cplane as 1.0.26. Features of the DiFX cluster system are listed as follows:

- DiFX 2.52, HOPS 3.18, nuSolve 0.6.4
- Head nodes: DELL R820 (E5-4610 CPU, 2.4 GHz, 2\*6 cores), 64 GB Memory, DELL R730 (E5-2623 CPU, 3.0 GHz, 2\*4 cores), 64 GB Memory.
- Computing nodes: 20 DELL R630 nodes, two socket Intel E5-2660 CPU (2.6 GHz, ten cores), 64 GB Memory, 400 cores in total
- I/O nodes: RAID6, 800 TB raw storage capacity
- Data playback units: three Mark 5A, three Mark 5B, and three Mark 6.
- 56 G Infiniband for internal computing network connection
- 1/10 G Ethernet for internal and external network connection

### 3 Staff

The people involved in the operation, development of the correlator, and VLBI digital backend are listed below.

#### 3.1 Operations Team

- Fengchun Shu: group leader, scheduler, experiment oversight
- Zhong Chen: e-transfer support, cluster administration
- Zhanghu Chu: media library
- Shaoguang Guo: Mark 6 maintenance
- Xuan He: DiFX operation
- Yidan Huang: DiFX operation, post-correlation technique development
- Tianyu Jiang: data playback, DiFX operation

- Wu Jiang: DiFX operation
- Xiuzhong Zhang: VLBI terminal and correlation technique development

Wu Jiang is no longer involved in regular geodetic VLBI data correlation from 2018 onward. He will put emphasis on some pilot fringe tests and astronomical data correlation.

#### 3.2 Technique Development Team

- Weimin Zheng: group leader, software correlator, and VLBI terminal development
- Jiangying Gan: FPGA programming
- Tetsuro Kondo: wideband bandwidth synthesis and correlators comparison
- Lei Liu: software correlator development
- Xiaochuan Qu: CDAS development
- Ping Rui: visualization programming and operation for CVN correlator
- Fengxian Tong: VLBI scheduling and modeling
- Li Tong: VLBI raw data simulation
- Yajun Wu: CDAS development
- Zhijun Xu: FPGA programming and hardware correlator development
- Juan Zhang: software correlator development and maintenance
- Renjie Zhu: CDAS development

Tetsuro Kondo from NICT joined the group in mid-2017 as a distinguished scientist, offered by the CAS President's International Fellowship.

## 4 Summary of Activities

### 4.1 DiFX Correlation

We use the latest stable version of DiFX and HOPS software for regular IVS data correlation. The DBedit software was replaced by vgosDBmake to generate database files in 2018. The vgosDB files are available at our ftp site<sup>1</sup>. We also produce FITS-IDI files which can be downloaded by the request of users.

<sup>1</sup> <http://202.127.29.4/vgosDB/>

For a few IVS schedule files (e.g., CRDS93) generated in VEX format, there was no source flux density information available. In order to provide baseline SNR statistics in the correlation report, we need to convert the schedule file to SKED format by adding source flux density information.

We introduced peculiar clock offsets to compensate instrumental delays of reference stations during the correlation procedure in early 2018. As shown in Figure 2, we analyzed all 98 correlated sessions, and derived clock biases of the Shanghai correlator, i.e., compensation errors with respect to the peculiar clock offset table maintained by Ed Himwich and used by the Washington correlator. In most of cases, the clock bias is less than 3  $\mu\text{s}$ . Only two sessions (AOV006 and AUG020) have clock biases greater than 5  $\mu\text{s}$ . We are trying to keep the correlator clock bias within 0.1  $\mu\text{s}$ .

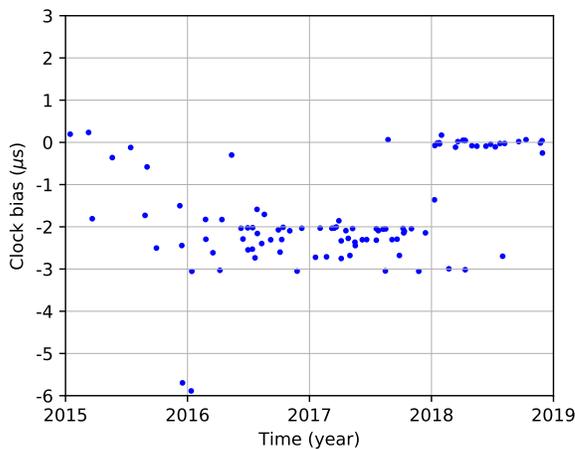


Fig. 2 Clock bias of Shanghai correlator over 98 sessions.

## 4.2 Development of the CVN Software Correlator

The CVN software correlator has implemented two new features: VDIF format decoding support and real-time fringe monitoring. It has been used to process single-band VDIF data acquired from VGOS stations in the Sheshan area. Good fringes were obtained.

To support the future space VLBI project, we have implemented the calculation of space-ground delay

model compatible with the new data format RDF. With the help of ASC, we have processed a set of RasioAstron space-ground VLBI data and successfully obtained good fringes.

We are developing and testing a GPU-version correlator. The processing data rate is 1 Gbps/station for ten stations totally. The GPU cluster includes four GPU-nodes. Features of each GPU-node are as follows:

- Node: 36 Intel Xeon CPU E5-2697 v4 @2.3GHz, 4\* NVIDIA K80;
- 56 G Infiniband for internal computing network connection.

## 4.3 CVN and K5 Correlators Comparison

We used the VLBI experiment K14349 observed on 2014/349 07h-08h UT to perform a comparison of the CVN and K5 correlators. Four stations, such as Nyales20, Seshan25, Tsukub32, and Wettzell, participated in the experiment.

Results obtained by the CVN software correlator have been compared with those obtained by the K5 software correlator. Earth-centered epoch correction and X clock offset correction were applied to K5 results. As a result, K5 and CVN show a good agreement with each other on observed values, such as fine (multi-band) delay, delay rate, and fringe amplitude. The average of the standard deviation of the differences between X-band fine delays is 7.6 ps. As for the delay rate, the average of the differences at X-band is  $0.00 \pm 0.09$  ps/s. As for the fringe amplitude at X-band, the average ratio (CVN/K5) is  $0.98 \pm 0.11$ .

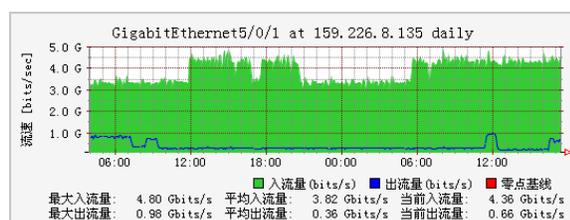
## 4.4 Chang'E 4 Tracking

China's Chang'E 4 spacecraft is the first probe to make a soft landing on the far side of the moon. Tianma65, Beijing, Kunming, and Urumqi stations participated in intensive VLBI tracking sessions from its launch on 8 December 2018 to its soft landing on 3 January 2019. We observed 22 tracking sessions in total. During the same time period, we also observed Chang'E 4 data relay satellite Queqiao which means "bridge of magpies" in 19 tracking sessions.

## 4.5 e-VLBI

The network link to Seshan25 and Tianma65 is 10 Gbps. The network link to the Urumqi, Kunming, and Beijing stations is 200 Mbps for spacecraft e-VLBI observations. In the Chang'E 4 lunar mission, we made real-time data transfers at a data rate of 128 Mbps for each station. However, for regular geodetic observations, the Chinese stations always ship modules to the Shanghai correlator.

In order to process IVS global sessions, we have established a network link to most of the IVS stations and correlators. The maximum data rate could be up to 4 Gbps. An example is shown in Figure 3.



**Fig. 3** A screenshot of e-VLBI data rate daily monitoring, where the output data rate is shown in blue and the input data rate is in green.

Except for Kokee and Matera, all other international stations e-transfer data to Shanghai. Since May 2018, we had module shipment issues due to customs clearance. Thus, Kokee data were shipped to Haystack and then e-transferred to Shanghai.

## 4.6 Experiments Correlated

Within the framework of the IVS, we correlated 33 sessions in 2017 and 26 sessions in 2018. Most of them are focused on VLBI absolute astrometry. There are no stringent requirements on data latency. More details can be found in Table 1.

It is worth noting that APSG sessions and some AOV sessions were scheduled by SHAO. So far we have correlated 98 IVS sessions with 33 participating stations distributed over the globe. The cumulative data volume is approximately 2.5 PB, collected from more than 600 station days. The top five stations with most

**Table 1** Statistics of experiments correlated.

Session Name	2017	2018
AOV	3	7
APSG	2	2
AUS-AST	14	6
IVS-CRF	6	5
IVS-CRDS	3	1
IVS-R&D	5	5

observing days are Katherine, Yarragadee, Hobart26, Warkworth, and Kunming.

In addition, we correlated some domestic VLBI experiments for geodesy or astronomy.

## 4.7 VEPS

We completed the first circle of the VLBI Ecliptic Plane Survey (VEPS) in 17 sessions by the end of 2017. Seshan25, Kunming, and Urumqi were core participating stations, while a few international stations, such as Kashim34, Hobart26, and Sejong, took part in the observations on an ad-hoc basis. The raw data from the stations is more than 900 TB in total. We detected 662 calibrator candidates from more than 4,000 observed sources.

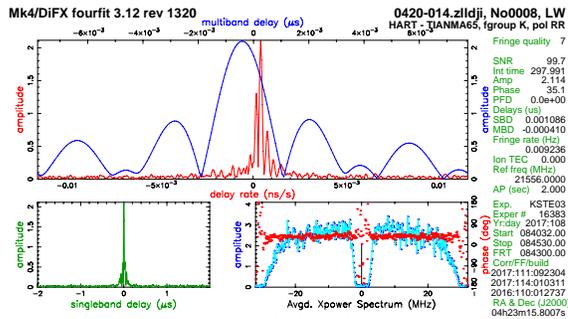
## 4.8 2 Gbps at S/X

We performed the first international 2 Gbps experiments at S/X dual band on 24 January 2018 (EPA001) and 10 February 2018 (EPA002). The participating stations were Chinese and Russian stations. Kashim34 joined in EPA002. Due to strong RFI at S-band, there were unusable channels and decreased sensitivity. Therefore, the results are not as good as what we expected.

## 4.9 K-band Test for Tianma65

We conducted a K-band fringe test with participation of Tianma65 and HartRAO on 18 April 2017. The observations were performed at a 2,048 Mbps data rate,

with 16 IF channels (8 USB and 8 LSB) and 2-bit sampling. Only RCP was used. Each IF channel has 32 MHz wide. Good fringes were detected as shown in Figure 4.



**Fig. 4** K-band fringes on the baseline Tianma65–HartRAO.

## 5 Future Plans

As the data correlation of AUA sessions is in transit to Vienna VLBI group, the number of IVS observing sessions correlated at Shanghai will be decreased. Currently, only 20 are scheduled in 2019. However, most of them will be observed at a 1-Gbps data rate.

The CVN correlator will be expanded into a general purpose correlator, and its performance will be updated by GPU acceleration. It will continue to support China’s follow-up series of lunar and deep space missions, as well as the space VLBI project.

Two VGOS antennas have been deployed in She-shan area. We are ready to make test correlation of VGOS data. Hopefully they will soon join in international VGOS experiments.

## Acknowledgements

We acknowledge the support of National Natural Science Foundation of China (Grant No. 11573056 and 11573057), and Fundamental Science Data Sharing Platform (DKA2017-12-02-09).